New Observations of Close Eclipsing Binary Systems with δ Scuti Pulsations

Garrison Turner
Big Sandy Community and Technical College, Prestonsburg, KY 41653; gturner0040@kctcs.edu

Ronald Kaitchuck
Ball State University Dept. of Physics and Astronomy, Muncie, IN 47306; rkaitchu@bsu.edu

John Holaday
Purdue University Dept. of Material Engineering, Lafayette, IN, 47907; jholaday@purdue.edu

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Abstract In this paper we present the detection of δ Scuti-type pulsations in three close eclipsing binary systems (EV Ori, FO Ori, X Tri) as part of a photometric observing campaign of fourteen such systems. These observations were done as part of an ongoing effort to find such objects as they are of great value for checking theoretical models of stellar characteristics against empirically determined parameters.

1. Introduction

δ Scuti stars have become of particular importance in the last few decades. They are intrinsic variables with generally low amplitudes (on the order of less than 100 mmag) and short periods (about 0.02 to 0.3 day). See Breger (2000) for a detailed review of the characteristics of δ Scuti stars. These stars allow for the study of their interiors through asteroseismology, thus allowing theoretical models to be checked against observational results. In particular, a recently discovered class of object involves an (Algol-type) binary system in which one of the components is a δ Scuti-type variable (Broglia and Marin 1974; Liakos *et al.* 2012). These objects were termed “oscillating eclipsing Algol-type binary systems,” or oEAs by Mkrtichian *et al.* (2004). Close binary systems allow for the determination of characteristics of each component in the system through photometric and spectroscopic observations, while studies of the pulsations allow for detailed asteroseismological studies of the pulsating component.

2. Observations

The targets for observation were chosen from a catalogue of possible oEAs given by Soydugan *et al.* (2006). FO Ori was found to have pulsation while

Table 1. Specifications for the instruments used for observations.

Instrument	*Diameter (m)*	*Focal Ratio*	*Camera*	*Field Scale arc sec/pixel*	*Field of View length (arc min)*	*width (arc min)*
BSUO Meade	0.4	f/6	SBIG ST-10XME	0.58	21.01	14.1
BSUO Celestron	0.3	f/11	SBIG STL-6303	0.47	24.34	16.26
SARA North	0.9	f/7.5	Apogee U42	0.4	13.86	13.86
SARA South	0.6	f/13.5	Apogee Alta E6	0.6	11.55	11.55

being observed for a separate program (see Kaitchuck *et al.* 2012). X Tri was observed in 2009 but pulsations were not detected in the study (Liakos and Niarchos 2009); however, they were detected in our campaign.

The observations for this project were taken between January and December of 2010. Data were collected with four different telescopes. The Ball State University Observatory (BSUO) houses two of the instruments. These include 0.4-m and 0.3-m diameter telescopes. Ball State University is also part of the SARA consortium which operates a 0.9-m telescope at Kitt Peak National Observatory and a 0.6-m telescope at Cerro Tololo in Chile. The SARA telescopes are of the Cassegrain design, while the BSUO telescopes are Schmidt-Cassegrains. Table 1 gives the specifications of each telescope and the CCD camera used.

Tables 2 and 3 describe the observing program for each star. Included are the target and comparison stars chosen, R.A. and Dec. coordinates (J2000), UT and Julian Dates for each observation session (with heliocentric correction applied), which telescope was used, and the number of images taken in each filter. Coordinates for each were obtained from the SIMBAD database.

All the observations made for this study were done using differential photometry. Because a typical star in the δ Scuti region on the HR diagram is of spectral type A5-F2, the best filters to use to detect pulsations are the B and V (pulsation amplitudes are filter-dependent with the B and V filters providing the highest amplitudes in this case). Images were reduced using the IRAF (Tody 1993) ccdred package, correcting for bias, dark, and flat-field effects. Differential photometry was performed with the AIP4WIN software package (Berry and Burnell 2006). All light curves that indicated eclipse phenomena were fit with quadratic polynomials to flatten the data set before the period analysis was performed. Only the in-eclipse portions of the light curves were fit with polynomials to remove orbital phenomena as the out-of-eclipse portions of the light curve did not need fitting. The errors on the data points represent the standard deviation on the check-comparison observations, as it is believed this is a more accurate representation of the true error rather than the errors calculated by AIP4WIN, which are underestimates.

Table 2. Coordinates for the target, comparison, and check stars.

Target		*Comparison*		*Check*	
R.A. (J2000) *h m s*	*Dec. (J2000)* *° ‘ “*	*R.A. (J2000)* *h m s*	*Dec. (J2000)* *° ‘ “*	*R.A. (J2000)* *h m s*	*Dec. (J2000)* *° ‘ “*
AD Her		HD 349426		TYC 1596-270-1	
18 50 00.3	+20 43 16.5	18 50 13.3	+20 45 01.6	18 50 18.5	+20 45 30
AT Peg		—		—	
22 13 23.5	+08 25 30.9	22 12 47.9	+08 33 21.4	22 12 56.4	+08 31 14.8
CZ Aqr		TYC 6396-1024-1		TYC 6396-872-1	
23 22 20.6	-15 56 20.4	23 22 24.0	-15 59 14.5	23 22 34.6	-15 55 20.4
EE Peg		—		HD 206015	
21 40 01.9	+09 11 05.1	21 40 17.3	+09 00 34.3	21 39 04.3	+09 03 23.0
EG Cep		HD 193834		HD 194400	
20 15 56.8	+76 48 35.7	20 14 43.9	+76 43 11.2	20 17 52.9	+76 40 07.4
EY Ori		Parenago 599		—	
05 31 18.4	-05 42 13.5	05 31 02.2	-05 37 27.5	05 30 59.6	-05 39 14.6
FO Ori		TYC 105-2415-1		HD 244077	
05 28 09	+03 37 23	05 28 35.4	+03 38 45.0	05 28 19.7	+03 36 25.9
QY Aql		HD 354962		TYC 1618-1054-1	
20 09 28.8	+15 18 44.7	20 09 25	+15 17 34	20 09 11	+15 21 49
RR Vul		TYC 2179-59-1		TYC 2179-613-1	
20 54 47.6	+27 55 05.7	20 54 37.7	+27 53 11.2	20 54 48.8	+27 57 54.2
SW CMa		TYC 5976-1216-1		TYC 5976-472-1	
07 08 15.2	-22 26 25.3	07 07 54.9	-22 23 26.1	07 07 53.8	-22 25 57.2
SY Cen		TYC 8991-1036-1		TYC 8891-616-1	
13 41 51.5	-61 46 10.1	13 42 04.6	-61 44 58.1	13 41 52.1	-61 44 35.2
UX Her		TYC 1557-1248-1		TYC 1557-440-1	
17 54 07.8	+16 56 37.8	17 54 06.6	+16 58 14.8	17 54 13.0	+17 04 37.8
V805 Aql		HD 177707		TYC 5715-940-1	
19 06 18.2	-11 38 57.3	19 06 16.3	-11 35 39.9	19 06 12.6	-11 33 18.3
X Tri		HD 122212		TYC 1763-2015-1	
02 00 33.7	+27 53 19.2	02 00 30.6	+27 47 05.9	02 00 37.8	27 55 10.8

3. Analysis and results

3.1. Observational results

Once generated, each light curve was processed and period-searched using the PERANSO (Vanmunster 2007) period analysis software package for periodic

Table 3. UT dates for the observations, start and end times in JD, instrument used, and number of images collected in each filter for each set of observations.

Target	*UT*	*JD Start 2455000*	*JD End 2455000*	*Instrument*	*B*	*V*
AD Her	25-Jun-10	372.7021	372.7669	0.3-m	—	27
	28-Jun-10	375.7534	375.8413	0.9-m	86	86
AT Peg	19-Aug-10	427.6592	427.7383	0.3-m	50	50
CZ Aqr	31-Jul-10	408.7623	408.9127	0.6-m	84	84
	8-Oct-10	477.7341	477.8246	0.6-m	89	84
	13-Oct-10	482.5072	482.6699	0.6-m	45	—
EE Peg	18-Jun-10	365.806	365.8565	0.3-m	—	48
EG Cep	17-Aug-10	425.7196	425.8094	0.3-m	31	31
EY Ori	17-Nov-10	517.7899	517.9638	0.6-m	464	—
	10-Dec-10	540.7472	540.8907	0.9-m	107	
FO Ori	3-Jan-10	199.587	199.9109	0.9-m	199	199
	8-Jan-10	204.6062	204.8927	0.9-m	168	204
	11-Jan-10	207.6431	—	0.9-m	129	180
QY Aql	1-Jul-10	378.7433	378.8872	0.6-m	60	60
	15-Jul-10	392.645	392.7995	0.4-m	—	70
	9-Sep-10	448.6848	448.7857	0.4-m	—	96
RR Vul	6-Oct-10	475.6726	475.7427	0.4-m	—	60
	7-Oct-10	476.5624	476.8155	0.4-m	—	104
SW CMa	7-Apr-10	293.5004	293.6583	0.6-m	—	318
SY Cen	31-May-10	347.4475	347.6513	0.6-m	—	162
UX Her	25-Jun-10	372.6583	372.846	0.4-m	—	93
V805 Aql	18-Jun-10	365.7374	365.7925	0.4-m	—	50
X Tri	6-Oct-10	475.7500	475.8708	0.4-m	—	101
	7-Oct-10	476.6976	476.8154	0.4-m	—	212

behavior between 0.01 and 0.3 day, which encompasses the accepted range of periods found in δ Scuti stars, using the Lomb-Scargle method (Lomb 1976; Scargle 1982).

An object was determined to have strong periodicity if the period window in PERANSO showed a dominant peak above the noise in the Lomb-Scargle statistic (theta) and if this peak was associated to only one (the central) peak of the spectral window (the peaks in the spectral window show how the data were sampled). Only peaks in the period spectrum that were not found to be artifacts of the observing schedule were deemed as possibly due to stellar pulsation.

Table 4. Orbital period P_{orb}, the pulsation period P_{pulse}, uncertainty, and amplitude in mmag for targets showing strong periodicity (Soygugan *et al.* 2006; Brancewicz and Dworak 1980).

Target	P_{orb} *(day)*	P_{pulse} *(day)*	*Uncertainty (day)*	*Amplitude (mmag)*
EY Ori	16.78781	0.103	0.002	10
FO Ori	18.80062	0.0292	0.0002	50
X Tri	0.97151	0.022	0.0002	20
CZ Aqr	0.86281	0.0331	0.0002	12
QY Aql	7.22961	0.1119	0.0024	12

Table 4 gives the results of the observational campaign, indicating the dominant pulsation period, uncertainty, and amplitude (all amplitudes indicated are half-amplitudes). Five objects were found to have strong periodicity, although two (CZ Aqr and QY Aql) were observed with better coverage by Liakos *et al.* (2012) and thus their result contains more certainty in the measurement of the periods. They determined pulsation periods of 0.02849 and 0.09385 day for CZ Aqr and QY Aql, respectively. The discrepancies between the results are likely due to better coverage by Liakos *et al.* (2012). It is difficult to precisely determine pulsation periods with such short time spans as obtained in this study. The remaining three were EY Ori, FO Ori, and X Tri. Figure 1 shows the light curves and Figure 2 shows the power spectra for EY Ori, FO Ori, and X Tri, respectively. Because data in only one filter were taken for EY Ori and X Tri, no other filters could be used for comparison. On the other hand, the power spectrum for the V data for FO Ori is shown in Figure 2, and period-searching the B data produced an identical period shown in Table 4.

3.2. Discussion and conclusion

This present work has sought to contribute to the total number of close eclipsing binary systems with a δ Scuti variable by reporting six new pulsation periods in eclipsing systems from a ground-based campaign. However, further observations on all of these objects is encouraged as short time spans on each object limit the accuracy and the resolution of the frequency analysis, in particular for those δ Scuti stars which undergo multi-periodic pulsations (a general behavior). Due to the uninterrupted data collection of the Kepler and CoRot satellites the numbers in this class of object should increase significantly in just a few years. Eclipsing systems with a pulsating component are important for their use as laboratories in which theoretical stellar models are able to be tested against observational results, thus this type of work has very serious implications for the understanding of stellar processes.

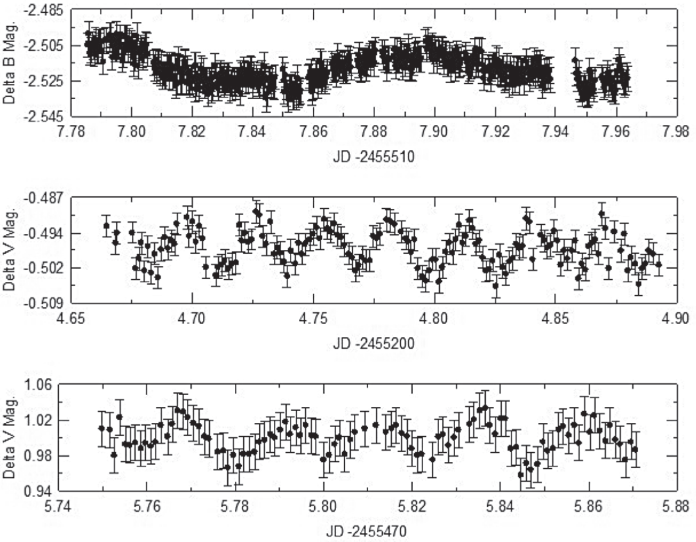

Figure 1. Light curves for EY Ori (top panel), FO Ori (middle panel), and X Tri (bottom panel) on the nights of 17-Nov-2010, 8-Jan-2010, and 6-Oct-2010, respectively. The top panel shows the ΔB magnitudes of EY Ori, while the middle and bottom panels show the ΔV magnitudes of FO Ori and X Tri.

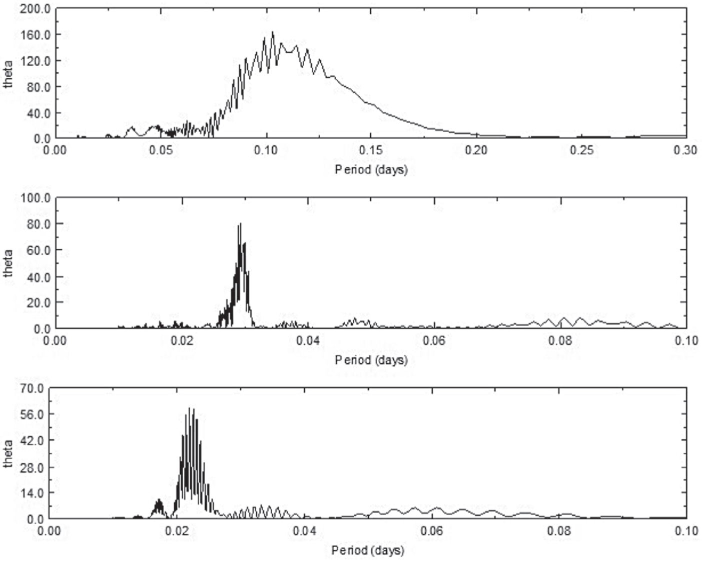

Figure 2. Power spectra for EY Ori (top panel), FO Ori (middle panel), and X Tri (bottom panel). The top panel shows the power spectrum for all of the B images of EY Ori. The middle panel and bottom panels show the power spectrums for the V images of FO Ori and X Tri, respectively.

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